HISTORICAL RÉSUMÉ OF MINE AND TUNNEL VENTILATION STUDIES BUREAU OF MINES, 1910-1949

BY G. E. McELROY

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G. E. McElroy 1/

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INTRODUCTION

The subject of mine and tunnel ventilation has two broad aspects - (1) what atmospheric conditions to obtain in underground openings and (2) how to maintain the desired conditions efficiently. The first relates primarily to quantity requirements of ventilating systems, whereas the second relates more particularly to pressure requirements. Both, therefore, determine power requirements, which is the deciding factor in any system of mine or tunnel ventilation.

Both divisions of the subject have received considerable attention from the Bureau of Mines since its inception in 1910 in the form of research, service, and correlation and dissemination of information. Numerous papers on various phases of the subject have been published, of which a selected list, numbered and arranged in chronological order by type of publication, will be found at the end of this paper. One of these, Technical Paper 705 (25),2/ gives a complete bibliography of Bureau of Mines publications dealing with health and safety. As indicated by the selected list of publications accompanying this paper, the health and safety aspects have received most of the attention devoted to this work, chiefly because these have been dominant factors in Bureau policy, but partly because these aspects lend themselves to laboratory research and small-scale field studies. Although considerable attention has also been devoted to the engineering aspects of mine and tunnel ventilation, there has been, in the opinion of the author, who has been engaged on this phase almost continuously for the last 30 years, only sporadic recognition of the vital effect this phase of the work could have on improving health and safety conditions. As a matter of fact, ventilation activities have constituted but a very minor part of the total work of the Bureau of Mines, as, except for a few years in the nineteen twenties, there have been only a few short intervals when more than two or three men were engaged in field work and a similar number in laboratory research directly related to mine gases or mine air.

WORK OF THE BUREAU BY PERIODS

1910-1921

In the early work of the Bureau, few specific field studies (1, 2) were made, and the emphasis was largely on safety, particularly as regards mine gases (3, 14, 15, 26, 27, 29, 115). Serious dust studies were started in the Joplin, Mo., district in 1914, where ventilation was not considered to be a problem. When these studies were continued in 1916 in the Butte, Mont., mines, where ventilation was a serious problem, the engineer assigned to the study was Dan Harrington, who developed a particular and intense interest in the health and safety aspects of ventilation, which continued

2/ Numbers in parentheses refer to items listed at the end of this paper.

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throughout his Bureau career successively as western district supervising mining engineer, Chief of the Safety Division, and, until his retirement in 1948, Chief of the Health and Safety Division. Other Bureau officials particularly interested in mine ventilation were Dr. G. S. Rice, Harrington's former chief to 1924 and chief mining engineer from the creation of the Bureau in 1910 until his retirement in 1937; Dr. R. R. Sayers, appointed Chief Surgeon in 1920, then Chief of the Health and Safety Branch, 1926-1933, and Director 1940-1947; and Dr. H. Foster Bain, Director 1921-1925. Dr. Rice's interest was mainly in the safety and engineering phases, Dr. Sayers' was along health lines, and Dr. Bain's was mainly in the engineering aspects.

During the period 1916-1921, Harrington continued a personal study of underground air conditions in Butte mines (4, 16) and directed a small corps of engineers and Public Health Service doctors engaged in field studies of dust-ventilation conditions in various western mining districts, on which many general (31, 41, 116, 117, 118, 119) and specific (32, 33, 34, 35, 36, 37, 38, 40, 42, 43, 51) publications were based.

Vehicular-Tunnel Ventilation Studies

Starting late in 1919 and continuing through 1921, an extensive investigation of the problems involved in the ventilation of vehicular tunnels was carried out in cooperation with the New York State and New Jersey Interstate Bridge and Tunnel Commissions and related to the ventilation of the Holland Tunnels, which were then being constructed under the Hudson River. This investigation was divided into four separate and distinct problems, as follows:

1. Amount and composition of exhaust gases from motor vehicles, conducted at the Pittsburgh Station, Bureau of Mines, under the direction of A. C. Fieldner.

2. Physiological effect of exhaust gases from motor vehicles, conducted at Yale University under the direction of Yandell Henderson, consulting physiologist to the Bureau.

3. Determination of empirical factors for calculating the pressure requirements for flow of air through concrete ducts, conducted in cooperation with the Engineering Experiment Station of the University of Illinois, Urbana, Ill., under the direction of A. C. Willard.

4. Determination of the relative merits of various methods of transverse ventilation for the Holland tunnels, conducted in a model tunnel constructed in the Bureau's Experimental Mine, Bruceton, Pa., under the direction of A. C. Fieldner, J. W. Paul, and R. R. Sayers.

Detailed results of problems 1, 2, and 4 and part of problem 3 have been published (13,127), but the major results of problem 3 have been summarized only briefly in the yearly reports of the two commissions

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involved. The Bureau had devoted a large amount of time and effort to these problems, which developed a continuing interest in toxic combustion gases (39, 58, 63, 66, 108, 112), including those in railroad tunnels (17, 46, 56, 60), and led to the development of a carbon-monoxide recorder (18) now widely used in vehicular tunnels and in industry. The fact that problem 3 had to be "farmed out", so to speak, because of lack of equipment and trained personnel, probably had something to do with the decision to conduct similar engineering investigations on the airways of the Experimental Mine, for which some equipment and experience resulted from the work on problem 4.

1922-1927

A comprehensive study of coal-mine ventilation factors was started in the Experimental mine late in 1921 under the author's direction, requiring considerable development and testing of instruments and methods of procedure. About the time the actual test program started, arrangements were made for the author to do similar work in cooperation with the Anaconda Copper Mining Co. in its metal mines at Butte, Mont. H. P. Greenwald then carried the Experimental Mine test work (6) to conclusion in 1923. The work at Butte was relatively more extensive and difficult and continued, with a few interruptions, into 1927. Rather elaborate tests were made of fan-tubing installations (48, 49, 50), of the resistance of typical metal-mine airways (5, 131), of laboratory and field methods of testing fans (19,135), of natural-draft ventilation (62), and of shaft air-temperature changes. Considerable attention also was devoted to a study of the application of air-conditioning to mines, then used only in one mine (52,126) in Brazil, but no tests were made. During short interludes in the Butte work, resistance tests were made on airways in an Indiana coal mine and in the Moffat Tunnel (133), Colorado, then under construction.

During the time the Butte work was in progress, and largely as a result of underground observations (45, 107, 109) made by Harrington and Sayers previous to the tunnel-gas studies, a very extensive series of laboratory tests on the effect of air conditions upon comfort was carried on at the Pittsburgh Station in cooperation with the Research Laboratory of the American Society of Heating and Ventilating Engineers, then quartered at that Station. The results, as reported in a series of Bureau of Mines (53, 54, 55), Public Health Service (110, 111), A.S.H.V.E. (121, 122, 123, 124, 125, 128), and other (138, 139, 140) publications, resulted in the formulation of a new concept - effective temperature - for expressing the interrelation of air temperatures, humidity, and movement on sensations of comfort. Later, the Research Laboratory of the A.S.H.V.E. made numerous additional tests to amplify this subject and developed charts for practical application of this information, which are published yearly in the A.S.H.V.E. "Guide."

During this same period in the early and middle nineteen twenties extensive field studies were made of blasting gases (7, 59) in metal mines and tunnels and of the occurrence of rock-strata gases (8) in the mines of the Cripple Creek District, Colorado. Tests also were made in the Experimental mine at Bruceton on the recirculation of gas caused by auxiliary fans as used in coal mines with results (134) that have guided coal-mine

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inspection policies in this matter. A number of papers on particular activities (20, 44, 47, 61) or of general interest (57, 90, 129, 130, 132, 136, 137) to mine ventilation appeared also during this period.

1928-1941

In the late twenties, the three mining groups within the Bureau concerned with health, safety, and mining methods, which had previously operated as a loosely integrated unit with free interchange of personnel and duties, drew apart and became separate entities with more sharply defined functions. The Health Division concerned itself mainly with laboratory studies, mostly of a pathological nature on the effects of gases, toxic vapors, and dusts. Few field studies were made, although interest in the physiological factors of mine ventilation (72, 76, 77, 80, 84, 97, 99) continued.

One large study in 1941 stemmed directly from the previous tunnel-gas investigations made in connection with the Holland Tunnels. At the request of the New York City Tunnel Authority, the Bureau conducted a series of wind-tunnel model tests to determine the rate of dilution of gases discharged from stacks (23), as a result of which the proposed design of the ventilation arrangements for the Manhatten end of the Battery-Brooklyn vehicular tunnel was radically altered.

During this period the Safety Division was concerned primarily with service work in both coal and metal mines, particularly coal mines, and though it gave only incidental attention to ventilation (11, 22, 73, 83, 88, 95, 98) a relatively large number of compilations and reviews (10, 74, 75, 78, 81, 86, 87, 91, 92, 93, 94, 96, 113, 114, 142) of both general and particular interest were published regarding the relationship between ventilation and mine safety.

During this period the Mining Division was primarily a research division for the study of mining methods, particularly metal-mining methods. Ventilation methods were studied in a number of mining districts (9, 21, 79, 89) and individual mines, the available information on several phases was correlated (64, 71, 82, 85), and a general bulletin on mine ventilation (12) was prepared, which is used not only as a textbook in many university mining courses but also appears in a condensed form as the section (141) on mine ventilation in the mining engineers' "bible" - Peele's Mining Engineers' Handbook. A special study was made of the conditions of jet flow at the discharge of fan-pipe lines in the Bureau's Mt. Weather adit, Bluemont, Va.; the results (65, 67) have been correlated with results of other jet research in a way that has served as a pattern for analyzing the results of later research in industrial ventilation.

1942-1949

Immediately preceding and during World War II the Bureau was engaged on many special war problems, several of which utilized its experience in mine ventilation. The most interesting and important problem (105), and

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one that fully utilized Bureau's experience in ventilation and toxic gases, was a study (in cooperation with the Bureau of Ships of the Navy) of the ventilation of tank landing (LST) ships as required to combat the hazard of carbon-monoxide poisoning of crew members during prolonged warming-up of tank and vehicle engines in closed holds.

Ventilation activities of the Mining Division were transferred to the Health Division (now Health Branch) in 1942. In recent years both the Health Branch and the Safety Branch have maintained an interest in ventilation problems, although mostly along educational lines (24, 28, 101, 102, 103, 106, 120, 143, 144, 145). Special studies have been made on the use of Diesel engines underground (68, 69, 100, 104); engineering studies have been made in coal mines, particularly on the application of pressure-surveying methods, on the "stall" troubles introduced by propeller fans, and on the application of fan-tubing auxiliary ventilation. Occasional surveys have been made in both coal and metal mines, and developments in both have been followed closely. Developments in the application of air-conditioning to mines have been followed continuously since 1936, for which purpose a special psychrometric chart (30, 70) was recently perfected after a number of unsatisfactory attempts dating back to the early work at Butte in the twenties; and developments in industrial ventilation, which often have direct application to special mine ventilation problems, are watched with interest.

CONCLUSION

The foregoing brief résumé of the work of the Bureau of Mines on mine and tunnel ventilation has been compiled mainly from the author's memory of events as they happened and as refreshed by lists of references. An attempt has been made to be strictly impartial in presenting this information, which is biased only by the fact that the author is more familiar with the work on which he was personally engaged than with work of equal importance that is not evident now in publications. A very considerable part of the work done by the Bureau of Mines on mine and tunnel ventilation has not found its way into print.

BUREAU OF MINES PUBLICATIONS DEALING WITH THE VENTILATION OF MINES AND TUNNELS

Bulletins

1. B. 83 - The Humidity of Mine Air, with Especial Reference to Coal Mines in Illinois, By R. Y. Williams. 1914, 69 pp., 2 pls., 7 figs.

2. B. 99 - Mine Ventilation Stoppings, with Especial Reference to Coal Mines in Illinois, by R. Y. Williams. 1915, 30 pp., 4 pls., 4 figs.

3. B. 105 - Black Damp in Mines, by G. A. Burrell, I. W. Robertson, and G. G. Oberfell. 1916, 88 pp.

4. B. 204 - Underground Ventilation at Butte, by D. Harrington. 1923, 131 pp., 3 pls., 42 figs.

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5. B. 261 - Resistance of Metal-Mine Airways, by G. E. McElroy and A. S. Richardson. 1927, 145 pp., 71 figs.

6. B. 285 - Coal-Mine Ventilation Factors, by H. P. Greenwald and G. E. McElroy. 1929, 106 pp., 47 figs.

7. B. 287 - Gases from Blasting in Tunnels and Metal-Mine Drifts, by F. D. Gardner, S. P. Howell, and G. W. Jones. 1927, 96 pp., 14 figs.

8. B. 317 - Rock-Strata Gases of the Cripple Creek District, Colo., and Their Effect on Mining, by E. H. Denny, K. L. Marshall, A. C. Fieldner, A. H. Emery, W. P. Yant, and W. A. Selvig. 1930, 66 pp., 21 figs.

9. B. 330 - Ventilation of the Large Copper Mines of Arizona, by G. E. McElroy. 1931, 145 pp., 42 figs.

10. B. 347 - Gases That Occur in Metal Mines, by D. Harrington and E. H. Denny. 1931, 21 pp.

11. B. 359 - Permissible Electric Cap Lamps and Ventilation in Certain California Mines and Water-Tunnel Construction, by S. H. Ash and J. H. Rankin. 1932, 36 pp., 12 figs.

12. B. 385 - Engineering Factors in the Ventilation of Metal Mines, by G. E. McElroy. 1935, 196 pp., 68 figs.

Monograph

13. M 1 - Ventilation of Vehicular Tunnels, by A. C. Fieldner, Yandell Henderson, J. W. Paul, R. R. Sayers, and others. 1927, 171 pp., 69 figs.

Technical Papers

14. T. P. 39 - The Inflammable Gases in Mine Air, by G. A. Burrell and F. M. Seibert. 1913, 24 pp., 2 figs.

15. T. P. 190 - Methane Accumulations from Interrupted Ventilation, with special Reference to Coal Mines in Illinois and Indiana, by H. I. Smith and R. J. Hamon. 1918, 46 pp., 2 pls., 5 figs.

16. T. P. 251 - Ventilation in Metal Mines, a Preliminary Report, by D. Harrington. 1921, 44 pp.

17. T. P. 292 - Tests of Gas Masks and Respirators for Protection from Locomotive Smoke in Railroad Tunnels, with Analyses of Tunnel Atmospheres, by A. C. Fieldner, S. H. Katz, and S. P. Kinney. 1922, 27 pp., 3 pls., 3 figs.

18. T. P. 355 - A Carbon Monoxide Recorder and Alarm, by S. H. Katz, D. A. Reynolds, H. W. Frevort, and J. J. Bloomfield. 1926, 35 pp., 3 pls., 13 figs.

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19. T. P. 447 - Experiments on Mine-Fan Performance, by G. E. McElroy and A. S. Richardson. 1929, 61 pp., 32 figs.

20. T. P. 507 - Explosions in Washington Coal Mines, by S. H. Ash. 1931, 52 pp.

21. T. P. 516 - Natural Ventilation of Michigan Copper Mines, by G. E. McElroy. 1932, 40 pp., 5 figs.

22. T. P. 608 - Safety Factors in Construction and Ventilation, Wawona Vehicular Tunnel, Yosemite National Park, Calif., by S. H. Ash. 1940, 34 pp., 21 figs.

23. T. P. 657 - Dilution of Stack Effluents, by G. E. McElroy, C. E. Brown, L. B. Berger, and H. H. Schrenk. 1944, 46 pp., 33 figs.

24. T. P. 678 - Design of Injectors for Low-Pressure Air Flow, by G. E. McElroy. 1945, 50 pp., 13 figs. (Abstracted in Heating and Ventilating, July 1947, pp. 82- 94.)

25. T. P. 705 - Bibliography of Bureau of Mines Publications Dealing with Health and Safety in the Mineral and Allied Industries, 1910-46, by Sara J. Davenport. 1948, 154 pp.

Miners' Circulars

26. M. C. 14 - Gases Found in Coal Mines, by G. A. Burrell and F. M. Seibert. 1914, 23 pp.

27. M. C. 16 - Hints on Coal-Mining Ventilation, by J. J. Rutledge. 1914, 22 pp.

28. M. C. 55 - Fires, Gases, and Ventilation in Metal Mines, Metal-Mine Accident-Prevention Course, Section 5. 1946, 94 pp., 42 figs.

Charts

29. Chart - Chart of Properties of Mine Gases, by G. A. Burrell. 1918.

30. Chart - Mine Air-Conditioning Chart, by G. E. McElroy. 1949.

Reports of Investigations

31. R. I. 2133 - Metal-Mine Ventilation and Its Relation to Safety and Efficiency in Mining Operations, by D. Harrington. 1920, 8 pp.

32. R. I. 2246 - Compressed-Air Blowers in Metal Mines, by D. Harrington, 1921, 5 pp.

33. R. I. 2273 - Compressed-Air-Operated Ventilation Doors in Arizona Copper Mines, by E. D. Gardner. 1921, 2 pp., 1 fig.

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34. R. I. 2275 - Rock-Strata Gases in Mines of the East Tintic Mining District, Utah, by G. E. McElroy. 1921, 3 pp.

35. R. I. 2282 - Hot High-Nitrogen Gas in a Metal Mine, by G. E. McElroy. 1921, 3 pp.

36. R. I. 2303 - Methane in California Gold Mines, by B. O. Pickard and E. D. Gardner. 1921, 6 pp.

37. R. I. 2309 - Compressed-Air Blowers as an Aid to Metal-Mine Ventilation, by R. V. Ageton. 1922, 5 pp.

38. R. I. 2320 - Performance of Fan-Pipe Installations in Metal Mines, by D. Harrington and G. E. McElroy. 1922, 4 pp.

39. R. I. 2338 - Physiological Effects of Exposure to Low Concentrations of Carbon Monoxide, by R. R. Sayers, F. V. Meriwether, and W. P. Yant. 1922, 6 pp.

40. R. I. 2355 - Determination of the Relative Comfort of Mine Working Places by Means of the Katathermometer, by D. Harrington and G. E. McElroy, 1922, 7 pp.

41. R. I. 2374 - Summary of Investigations of Dust and Ventilation in Metal Mines, by D. Harrington. 1922, 6 pp.

42. R. I. 2426 - Fire and Ventilation Doors in Metal Mines, by D. Harrington. 1922, 5 pp., 1 fig.

43. R. I. 2427 - Rock-Strata Gases in Mines of a Nevada Mining District, by E. D. Gardner. 1922, 4 pp.

44. R. I. 2448 - Preliminary Investigation of Brattice Cloth Used in Coal Mining, by G. S. Rice, J. W. Paul, and E. H. Denny. 1923, 4 pp.

45. R. I. 2464 - Physiological Effect of High Temperatures and Humidities With and Without Air Movement, by R. R. Sayers and D. Harrington. 1923, 7 pp., 1 fig.

46. R. I. 2494 - Atmospheric Conditions and Physiological Effects Produced on Trainmen by Locomotive Smoke in the Aspen and Wasatch Tunnels of the Union Pacific Railroad, by S. P. Kinney. 1923, 13 pp., 1 fig.

47. R. I. 2505 - Sulphur Trioxide Smoke Tubes for Determining Air Currents, by S. H. Katz and J. J. Bloomfield. 1923, 1 p., 1 fig.

48. R. I. 2509 - Experiments on Fan-Pipe Installations at Butte, Mont., by G. E. McElroy and A. S. Richardson. 1923, 14 pp.

49. R. I. 2527 - Air-Measurement Methods for Experimental Work on Fan-Pipe Installations, by G. E. McElroy and A. S. Richardson. 1923, 18 pp., 10 figs.

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50. R. I. 2540 - Friction Factors for Fan Piping Used in Mine Ventilation, by G. E. McElroy and A. S. Richardson. 1923, 15 pp., 5 figs.

51. R. I. 2551 - Distribution of Air in Metal-Mine Ventilation, with Especial Reference to Flexible-Tubing Methods, by D. Harrington. 1923, 11 pp.

52. R. I. 2554 - Cooling of Mine Air, by T. T. Read and F. C. Houghten. 1923, 19 pp.

53. R. I. 2563 - Effective Temperatures for Still-Air Conditions and Their Application to Mining, by F. C. Houghten, C. P. Yaglaglou, and R. R. Sayers. 1924, 10 pp., 8 figs.

54. R. I. 2565 - The Katathermometer - Its Value and Defects, by W. J. McConnell and C. P. Yaglaglou. 1924, 12 pp., 3 figs.

55. R. I. 2584 - Some Effects on Man of High Temperatures, by W. J. McConnell and R. R. Sayers. 1924, 13 pp., 8 figs.

56. R. I. 2624 - Temperatures in Cabs of Freight Locomotives Passing Through Tunnels of the Chesapeake & Ohio Railway, by S. H. Katz and E. G. Meiter. 1924, 8 pp., 6 figs.

57. R. I. 2637 - Some Features of Ventilating Fans at 164 Coal and Metal Mines, by D. Harrington and M. W. von Bernewitz. 1924, 5 pp.

58. R. I. 2661 - Exhaust Gases from Engines Using Ethyl Gasoline, by R. R. Sayers, A. C. Fieldner, W. P. Yant, B. G. H. Thomas, and W. J. McConnell. 1924, 24 pp., 3 figs.

59. R. I. 2739 - Gases from Blasting in Heavy Sulphides, by E. D. Gardner, G. W. Jones, and J. D. Sullivan. 1926, 8 pp.

60. R. I. 2858 - Tests of Atmospheres in Chesapeake & Ohio Railway Tunnels Between Clifton Forge, Va., and Hinton, W. Va., by R. R. Sayers, L. B. Berger, and W. P. Yant. 1928, 19 pp., 1 fig.

61. R. I. 2872 - The Use of Brattice Cloth in Coal Mines, by G. S. Rice and C. W. Owings. 1928, 8 pp.

62. R. I. 2890 - Determining the Air-Flow Resistance of a Small Shaft Mine by Natural Draft, by G. E. McElroy and A. S. Richardson. 1928, 15 pp., 2 figs.

63. R. I. 2908 - Carbon Monoxide from Automobiles Using Ethyl Gasoline, by W. P. Yant and L. B. Berger. 1929, 8 pp.

64. R. I. 3298 - Charts for Determining the Performance of Centrifugal Fans, by G. E. McElroy. 1936, 30 pp., 35 figs.

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65. R. I. 3531 - Air Flow at Discharge of Fan Pipe Lines in Mines. I. 10-inch Line in Development End, by G. E. McElroy. 1940, 14 pp. 8 figs.

66. R. I. 3585 - Carbon Monoxide and Particulate Matter in Air of Holland Tunnel and Metropolitan New York, by W. P. Yant, Edward Levy, R. R. Sayers, Carlton E. Brown, C. E. Traubert, H. W. Frevert, and K. L. Marshall. 1941, 69 pp., 28 figs.

67. R. I. 3730 - Air Flow at Discharge of Fan-Pipe Lines in Mines. II. Effect of Size and Shape of Pipe and of Adjacent Walls on Velocity and Entrainment Ratios, by G. E. McElroy. 1943, 30 pp., 12 figs.

68. R. I. 3887 - Observations on the Use of a Diesel Freight Locomotive Through a Railroad Tunnel, by L. B. Berger and L. H. McGuire. 1946, 20 pp., 5 figs.

69. R. I. 4032 - Diesel Engines Underground. VI. Use of Diesel Locomotives in Construction of the Delaware Aqueduct: Effect of Exhaust Gases Upon Quality of Tunnel Air, by L. B. Berger, M. A. Elliott, John C. Holtz, and H. H. Schrenk. 1947, 26 pp., 3 figs.

70. R. I. 4165 - A Mine Air-Conditioning Chart, by G. E. McElroy. 1948, 23 pp., 7 figs.

Information Circulars

71. I. C. 6086 - Why, When, and How to Make Ventilation Surveys of Metal Mines, by G. E. McElroy. 1928, 12 pp.

72. I. C. 6089 - Physiological Factors of Mine Ventilation, by R. R. Sayers. 1928, 16 pp.

73. I. C. 6106 - Auxiliary Power Units for Fan Operation, by F. E. Cash. 1929, 4 pp.

74. I. C. 6126 - Some Phase of Coal-Mine Ventilation, by J. J. Forbes and M. J. Ankeny. 1929, 18 pp.

75. I. C. 6136 - Progress in Metal-Mine Ventilation, by D. Harrington. 1929, 18 pp.

76. I. C. 6196 - Physiological Factors of Mine Ventilation, by R. R. Sayers. 1929, 17 pp.

77. I. C. 6245 - Effect of Abnormal Air Conditions on Mine Workers, by R. R. Sayers. 1930, 22 pp.

78. I. C. 6246 - Data on Metal-Mine Ventilation in 1929, by D. Harrington. 1930, 22 pp.

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